



No previews are good news: Using preview search to probe categorical grouping for orientation

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Abstract

We used the preview search procedure (Watson, D. G., & Humphreys G. W. (1997). Prioritising selection for new objects by top-down attentional inhibition of old objects. *Psychological Review*, 104, 90–122.) to examine distractor grouping in visual search for categorically-defined targets in the orientation dimension (Wolfe, J. M., Friedman-Hill, S. R., Stewart, M. I., & O'Connell, K. M. (1992). The role of categorization in visual search for orientation. *Journal of Experimental Psychology: Human Perception and Performance*, 18, 34–49). Participants searched for a relatively steep target presented amongst distractors of two shallow orientations. In a preview condition, the different distractors were presented in different time steps and search was found to be worse than a full-set baseline (Experiment 1). Further experiments determined this was not due to attentional capture by new distractors that were steeper than old items, nor to participants using different search strategies in the preview and full-set baselines. However, there were costs to performance when the old distractor group differed in orientation from the new distractors. We attribute the results to the preview condition disrupting grouping between distractors, with the different distractor groups then competing for selection with the target. An examination of the time-course of the preview effect suggested that grouping and segmentation was fast-acting, and separate from a process such as visual marking, involving the slow suppression of distractors over time. Under asynchronous presentation conditions, preview and new distractors that differ from the target orientation category, can compete rather than cooperate in grouping.

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1. Introduction

In a standard search procedure, where all the items appear together, performance can be affected by grouping between the target and distractors, and by grouping between distractors themselves (Duncan & Humphreys, 1989, 1992). Grouping between distractors can enable them to be rejected in a single step, even if they are relatively similar to the target. To understand search then, it is important to delineate how grouping processes operate. However, due to the presence of multiple grouping relations between the different items in standard search, it is often difficult to study effects of distractor grouping sepa-

rate from effects of target–distractor grouping. One way to address this problem is through the study of so-called ‘preview search’, in this paradigm sets of distractors are separated in time as well as space (presenting one set of distractors prior to the others; Watson & Humphreys, 1997; Watson, Humphreys, & Olivers, 2003). Previously, the preview procedure has been used to examine temporal parameters in search (e.g., the duration needed to segment old from new items; see Humphreys et al., 2004; Watson & Humphreys, 1997). However, the paradigm is also useful for studying grouping because, when the presentation of different distractors is staggered over time, grouping within one set of distractors can be isolated from grouping between the different sets (cf. Braithwaite, Humphreys, & Hodsoll, 2003; Braithwaite, Humphreys, & Hulleman, 2005). The effects of grouping between the sets of distractors can be evaluated, since such grouping effects can be

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reduced (and perhaps even eliminated) under preview conditions. Our aim here is to use this paradigm to assess categorical grouping within the orientation dimension.

Wolfe, Friedman-Hill, Stewart, and O'Connell (1992) showed that visual search was facilitated when a target was categorically different from the orientations of the distractors. They manipulated the orientation of the search displays as a whole whilst maintaining the orientation differences between the individual display elements. In a non-categorical search task, requiring detection of the 'steepest' item in the display, the target appeared 10° from the vertical meridian and the distractors at -30° and 70° (positive values reflect tilt to the right of the vertical, and negative to the left). Present and absent search slopes were 26 and 50 ms/item, respectively. In contrast, when the target differed 'categorically' from the distractors, being the uniquely 'steep' item (the target was at -10° from vertical and the distractors at -50° and 50°), search slopes were greatly reduced to 6 and 11 ms/item on present and absent trials. Note that the increase in search efficiency occurred despite the fact that the difference in orientation between the target and distractors remained the same across the conditions, at 40° and 60° from the target, Wolfe et al. proposed that orientation search could benefit if the target and distractors could be classified as categorically different—for example, if the target is the sole steep item and the distractors are all shallow. The investigators went on to show that left and right tilted descriptions were also useful, and thus proposed that orientation was coded according to the categories steep, shallow and left and right tilt.

In a recent paper, Hodsoll and Humphreys (2005) extended this work by asking whether the categorical effects of orientation on search were dependent on target foreknowledge. They compared the effect of orientation targets being categorically unique or not in known and unknown search conditions. In the known search condition participants were informed of the target identity via a word cue and a categorical advantage was evident for uniquely steep and shallow items. However, in an unknown condition, where the target was defined as the only item in the display with a unique feature value, no advantage for uniquely shallow or steep targets was found. Hodsoll and Humphreys concluded that top-down processes modulated effects of categorical perception in the orientation dimension. For example, an orientation-defined target may be detected efficiently not simply because it uniquely activates a categorically distinct channel (cf. Foster & Ward, 1991), but also because participants are set to monitor this channel (Hodsoll & Humphreys, 2005).

However, it may also be that, when a target is categorically different from distractors, there is a contribution to search from within-category distractor grouping, enabling the distractors to be efficiently rejected together. For example, in categorical search tasks, not only does the target differ in category from individual distractors, but, typically alongside this, the distractors all belong to a common category (the contrast to the target's category). Search can then be facilitated

by grouping between the distractors (Duncan & Humphreys, 1989). Wolfe and Friedman-Hill (1992) investigated the role of symmetry in search for orientation. They found that search performance was better when orientation distractors were symmetrical about the horizontal or vertical meridians. It may be then that distractor grouping has a role to play in category effects in search.

We evaluated this possibility by having participants carry out a preview search for a categorically orientation-defined target. The target was always the steepest item in the display (10° left of vertical) and it was presented along with two sets of distractors (in Experiment 1 70° left and 50° right of vertical; in Experiments 2 through 5, 50° right and left of vertical). In a full-set search condition, all the items were presented together. In the preview search condition, the two types of distractors were separated across time. All accounts of preview search assume that, in the preview condition, grouping between the distractors should be reduced (see Donk & Theeuwes, 2001; Jiang, Marks, & Chun, 2002; Watson et al., 2003). However, if between-distractor grouping normally contributes to search, then it is possible that performance could be disrupted in the preview condition compared to the full-set baseline. We report just this result. Experiment 1 demonstrates a preview cost relative to a full-set baseline. Experiment 2 showed it was not due to an anticipatory set to steep items leading to capture by new distractors steeper than the preview distractors but shallower than the target. However, in both Experiments 1 and 2 the preview condition was also slower than a half-set baseline, when just the new items were presented. Note that, in the half-set baseline, there should not be a benefit from grouping with the extra distractors present in the full-set baseline, so a preview cost relative to the half-set baseline cannot just be due to a loss of grouping but must be due to another factor. Experiment 3 used identical distractors in the preview and new search displays, eliminating a difference signal between the old and new distractors. In this circumstance, there was no search cost in the preview relative to the full-set baseline, moreover, preview displays were now faster than the half-set baselines. This suggests that old distractors could enter into grouping with new items when they would not interfere with search. Further, the preview costs relative to the half-set baseline may be linked to the presence of a difference signal between the temporally segmented old and new items, which would not affect the half-set baseline. In Experiment 4 we eliminated the possibility that the preview cost relative to the full-set baseline could be due to participants adopting different search strategies. We also further confirmed that the preview cost relative to the half-set baseline was minimised when a difference signal could not be computed between the old and new distractor groups. These data indicate that grouping between elements with the same categorical orientation can take place (e.g., in the full-set baseline), but difference signals between distractor groups can disrupt search (under preview conditions). Experiment 5 further showed that segmentation of old and new items into separate groups took place rapidly, with previews presented for short dura-

tions, with effects of differences between the old and new distractors then decreasing as the preview duration increased. This last result is consistent with a contribution from ‘visual marking’ (cf. Watson & Humphreys, 1997), when old distractors could interfere with performance (see also Humphreys et al., 2004). Taken together, the data reveal the contribution of between-distractor grouping to categorical orientation search, and they throw new light on the mechanisms underlying the preview effect.

2. Experiment 1: Preview search for orientation-defined targets

Experiment 1 provides data on the basic results. Participants received a preview of old distractors in one orientation, followed by a set of new distractors with a different orientation and a target that was steeper than the other stimuli (see Fig. 1). This preview condition was compared with a full-set baseline, where all the items appeared together, and a half-set baseline where stimuli equivalent to just the new search set were presented. If grouping between distractors facilitates search for a categorically-different target (the steep item), then preview search may be worse than the full-set baseline condition because any grouping of the old and new distractors is disrupted. Furthermore, if segmentation of the old and new distractors introduces competition between these stimuli, then there may also be a preview cost compared with the half-set baseline, when only the new items were presented. Here we report preview costs relative to both baseline conditions.

2.1. Method

2.1.1. Participants

Twenty-three human females and 7 males between the ages of 18 and 33 (all but 3 right handed) participated

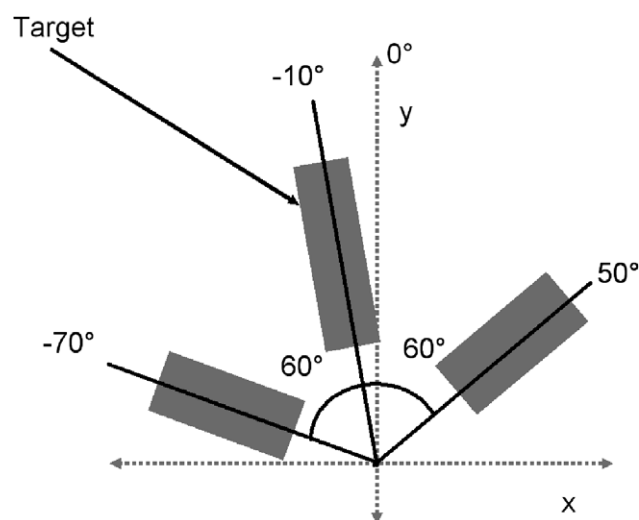


Fig. 1. The orientations of target (10°L) and distractors (70°L and 50°R) for Experiment 1, with the y-axis as the origin.

in the study. All had normal or corrected-to-normal vision.

2.1.2. Apparatus

The experiment was run on a Windows PCs with a 650-MHZ Pentium III processor, using a Philips 109S monitor. Presentation software (release 0.5 and above) from Neurobehavioral Systems was used to display the stimuli and record reaction times (RTs).

2.1.3. Stimuli

The stimuli used were variously oriented rectangles of dimensions 74 by 26 pixels on a standard 1028 by 762 SVGA display, subtending 1.27° of visual angle lengthways and 0.52° along the shorter axis for participants sat approximately 0.75 m from the monitor. Search displays consisted of items placed randomly on a virtual 5 by 5 matrix, subtending 8.15° visual angle. The target was a rectangle rotated 10° left of the vertical axis. There were two types of distractor: a distractor rotated 50° right of the vertical and a rectangle rotated 70° left of the vertical (see Fig. 1).

2.1.4. Design

There were two preview conditions, determined by which distractor was in the preview and which distractor in the search display. In preview condition A, the 50°R distractors appeared first, and the 70°L distractors appeared with the target. In preview condition B, 70°L distractors appeared first and the 50°R distractors were presented with the target (see Fig. 2a and b). Each of these previews was compared with the corresponding half-set baseline, where just the new items appeared. There was also a full-set baseline, where all the items were presented

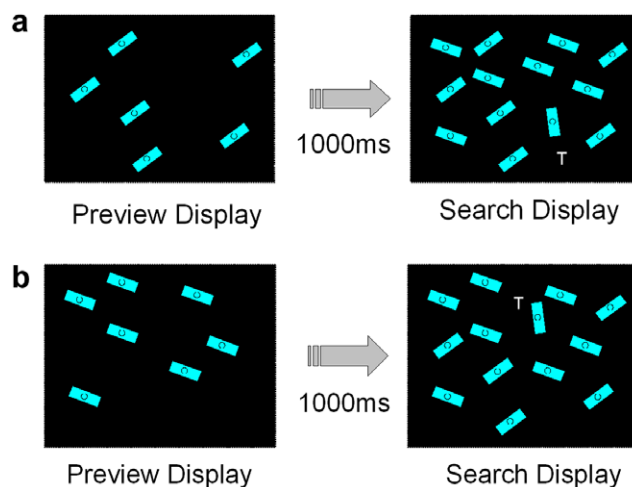


Fig. 2. (a) The sequence of a trial for preview condition A (70°L), Experiment 1. The preview consists of 50°R distractors followed by the target with 70°L distractors. (b) The sequence of a trial for preview condition B (50°R), Experiment 1. The preview consists of 70°L distractors followed by the target with 50°R distractors.

together. In the full-set baseline there were two display sizes, with 12 and 24 items. In the half-set baseline, there were 6 or 12 items present. The preview conditions involved presenting first either 6 or 12 items, which were respectively followed by 6 or 12 new items. If the old items have no impact on search, performance should be as equally efficient in the preview and half-set baselines. If the old items are not ignored, then search in the preview condition may be similar to that in the full-set baseline. To maximise the data collected on target present trials, a compound search task was used. Participants responded as to whether a break in a small circle centred within the target was at the circle's top or bottom. Note that all distractors had circle with breaks oriented towards the top or bottom also, giving an overall distribution of 50% top and 50% bottom. Preview studies have demonstrated a standard preview benefit with similar tasks (e.g. [Olivers, Humphreys, Heinke, & Cooper, 2002](#)).

2.2. Procedure

The preview conditions were presented over separate blocks of trials, in pseudo-random order. Each trial commenced with the appearance of a central fixation cross. For the baseline conditions, the search display appeared after the fixation-cross had been visible for 400 ms. For the preview display conditions, trials proceeded as follows. The fixation-cross appeared for 400 ms, followed by the preview distractors (left or right oriented rectangles for preview conditions A or B, respectively) for 1000 ms and subsequently, the second or search set of distractors appeared with the target (see [Fig. 2](#)). In the case of the preview condition trials, participants were instructed to keep their eyes centrally fixated during the preview display, i.e. until the search display appeared. For all trials, the display remained visible until participants responded or 10,000 ms had passed. A new trial commenced after 750 ms. Participants responded to the up/down location of the break in the black circle in the middle of the target element. Half of the participants responded 'f' if the gap in the circle was at the top and 'j' if it was at the bottom; the other half pressed 'j' and 'f' for top and bottom respectively. A short beep indicated when participants made an error. For each preview and distractor identity condition there were 96 trials, giving 24 trials for each response and display size condition. This gave a total of 480 trials pre-participants.

2.3. Results

A modified RT outlier procedure with a moving criterion ([Van-Selst & Jolicoeur, 1994](#)) removed 3.67% of correct RTs. The mean correct RTs by descriptive experimental condition are shown in [Fig. 3](#); the descriptive statistics for the search functions are presented in [Table 1](#) and errors in [Table 2](#).

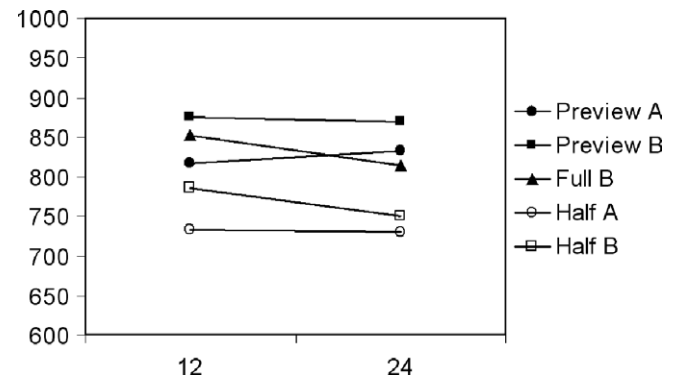


Fig. 3. Mean correct RTs for Experiment 1, preview conditions A (70°L search distractors) and B (50°R search distractors), half-element baselines A and B and the full-element baseline. RTs shown are for display sizes 12 and 24.

Table 1

Mean correct RTs in ms and slopes in ms/item for Experiment 1, preview conditions A and B, half-element baselines A and B and the full-element baseline

Condition	A (70°L)		B (50°R)		Full
	Preview	Half	Preview	Half	
Mean	824.5	732.5	872	768	833
Slope	1.25	−0.5	−0.5	−6	−3.2

RTs shown averaged over both display sizes.

Table 2

Percentage errors for Experiment 1, preview conditions A and B, half-element baselines A and B and the full-element baseline

	A (70°L)		B (50°R)		Full
	Preview	Half	Preview	Half	
12	7	6.4	6.7	8.1	7.3
24	6.6	8.3	8.3	6.6	7.9

2.3.1. Half-set baselines

The mean correct RTS for the half-set baseline conditions were compared in a two-way ANOVA (2 × 2) with distractor condition A and B (70°L and 50°R) and display sizes (6 and 12 items). RTs for condition A (731 ms) were faster than condition B (767 ms), although this difference was only marginally significant, $F(1,29) = 4.13$, $p = .051$. Overall, search RTs for display size 12 were slower than display size 24, $F(1,29) = 7.64$, $p < .01$, but this was qualified by a two-way interaction between display condition and display size, $F(1,29) = 8.95$, $p < .01$. As can be seen in [Fig. 3](#), whilst the search slope for the condition A distractors (70°L) was flat, the search slope for condition B (50°R) was negative (−6.5 ms/item).

2.3.2. Preview vs. half-set baselines

A three-way ANOVA on RTs assessed the effects of preview condition (preview and half-baseline), display

condition A and B (70°L or 50°R for search set distractors), and display size (12 or 24). RTs were 99 ms slower in the preview condition than the half-element baseline, $F(1,29) = 45.925$, $p < .001$, and were 42 ms slower overall in condition B 50°R as opposed to condition A 70°L, $F(1,29) = 8.163$, $p < .01$. Display size had no significant impact on search RTs. There were two significant interactions. First, there was an interaction between distractor condition and display size, RTs decreased with larger display sizes for the condition B 50°R search distractors but not for the condition A 70°L distractors. Secondly, a borderline-significant two-way interaction between preview condition and display size was evident as RTs decreased from 12 to 24 items for the half-set baseline conditions but not for the preview conditions, $F(1,29) = 4.073$, $p = .053$. No other interactions approached significance.

2.3.3. Preview condition A (70°L) vs. full-set baseline

Mean correct RTs for preview condition A and the full-set baseline, as a function of the display size, were contrasted in a two-way ANOVA. There was no main effect of preview or display size, but there was a preview by display size interaction, $F(1,29) = 4.69$, $p < .05$. Fig. 3 shows that a benefit for preview search over the full baseline is only apparent at display size 12.

2.3.4. Preview condition B (50°R) vs. the full-set baseline

Interestingly, in preview condition B RTs were 38 ms slower than the full-set baseline, $F(1,29) = 5.65$, $p < .05$. There was no main effect of display size or interaction between display size and preview.

2.3.5. Errors

Equivalent analyses on errors to those described above for RTs showed no significant effects, indicating the results described above were not due to a speed–accuracy trade-off (see Table 2).

2.4. Discussion

2.4.1. Baseline conditions

Search showed some variation in the half-set and full-set baselines. When only the left oriented (70°L) distractors were present, search was easier than when only the right (50°R) distractors were present. On the other hand, a negative effect of display size was evident for the 50°R distractors in the full baseline condition; whilst search slopes with 70°L distractors were flat. One explanation for the mean RT differences here is that the ease of search is reliant on the degree to which the distractors interfere with the categorically tuned ‘steep channel’ activated by the target (see Hodson & Humphreys, 2005; Wolfe et al., 1992). The 50°R distractors were nearer the steep category than the shallower 70°L distractors, and there was a consequent cost in RT when the 50°R distractors appeared. The argument for competition for a ‘steep’ orientation channel can also explain why a negative slope

emerged for more difficult baseline conditions. A negative slope in search can be attributed to the benefit of having more items which can form a stronger group (Bacon & Egeth, 1991), or local difference computations being used to distinguish target and distractor stimuli (Bravo & Nakayama, 1992; Sagi & Julesz, 1987). Grouping or local difference computations may play little part in search if the target uniquely activates a ‘steep’ orientation channel (in the easier conditions here); flat search functions emerge in this case. However, when there is competition for selection from distractors within the ‘steep’ orientation channel (i.e. when the distractors are near or above 45°), grouping or local difference computations have time to contribute to search performance.

For the full-set baseline search with heterogeneous distractors, search slopes were also negative at -3.25 ms/item but search was overall more difficult than in the half-set baselines. The effects of categorical similarity may also contribute this contrast in performance. According to this account, search in the heterogeneous (full-set) baseline may be more difficult than when 70°L distractors are used (due to competition in target selection from 50°R distractors), but easier than the 50°R condition (since 70°L distractors compete less for selection with the target). In terms of search slope this was the case (see Table 1), however, overall search was slower in the full than both half-set baselines. We attribute this to stronger distractor grouping taking place with homogeneous distractors, even when they are similar to the target (with 50°R), whereas grouping is disrupted with heterogeneous distractors—even if the heterogeneous distractors all fall within the same orientation category (Duncan & Humphreys, 1989). Using a signal detection task, Rosenholtz (2001) showed that there was better detection of a target defined by its orientation relative to homogeneous distractors than detection of the target amongst heterogeneous distractors, even when target–distractor similarity decreased with the homogeneous displays. Grouping of similar distractors in the same orientation category (Wolfe & Friedman-Hill, 1992) may allow efficient search in the full-set baseline, but if the grouping process is slowed by heterogeneity then there will be an overall cost on RTs, as shown in Table 1.

2.4.2. Preview conditions

Given that prior studies have always reported preview benefits, our data were surprising, but nevertheless clear. Only preview condition A (50°R distractors first) showed a reliable preview benefit at set size 12 compared to the full-set baseline. Moreover, preview condition B (when 70°L distractors appeared first) generated a substantial cost relative to the full-set baseline (an effect of 38 ms). To the best of our knowledge, this is the first time that a negative effect of preview search has been reported, relative to when all the items appear simultaneously.

So what causes this unusual pattern of performance? Our study differs from most preview experiments, where search has typically been investigated in more difficult

search conditions, when RTs are positively related to the number of display items¹ (Olivers, Watson, & Humphreys, 1999; Theeuwes, Kramer, & Atchley, 1998; though see Gibson & Jiang, 2001). However, the positive relationship between the number of display items and RTs means that in the preview, attending a subset of new items effectively eliminates the preview items from search, with a consequent reduction in RTs. However, search for orientation targets here is spatially parallel and facilitated as more items are added to the display (evidenced by the negative search slopes in the baseline conditions). Since, in this case, additional distractor items are beneficial to search, any process which reduces their effect will have a negative impact on search.

One account of why the preview benefit was either eliminated (preview A, 70°L search distractors) or reversed (preview B, 50°R search distractors) here is that, in the full-set condition, search profited from grouping between the two sets of distractors. Although the distractors are not identical, they were both relatively shallow and had to be discriminated from a target that was steep. The distractors could have been grouped together on the basis of their belonging to the same orientation category, facilitating their rejection from the target (cf. Duncan & Humphreys, 1989). This proposal is consistent with a negative search slope in the full-set condition if grouping increases with larger display sizes. Previous studies demonstrating beneficial effects of previews on search have been accounted for in various ways; including inhibitory visual marking of old items (see Section 1; Watson & Humphreys, 1997), temporal segmentation into old and new distractor groups (Jiang et al., 2002), and attentional capture through new onsets (cf. Donk & Theeuwes, 2001). Each account holds that the selection of the new stimuli should be prioritised, and consequently any grouping between the two types of distractor may be disrupted. If grouping has a beneficial effect in the full-set baseline, then performance may suffer as now observed.

However, an account simply in terms of grouping in the full-set baseline cannot explain why there should be a cost in the preview condition, when at the same time there was an advantage for the half-set baselines relative to the full-set baseline, Fig. 2 (half-set condition A 70°L vs. full-set baseline, $F(1, 29) = 23.48$, $p < .001$; half-set condition B 50°R vs. full-set baseline, $F(1, 29) = 16.46$, $p < .001$). If the old items were simply eliminated from processing (or if attention was simply captured by the new stimuli; cf. Donk & Theeuwes, 2001), performance in the preview condition should have been equivalent to the half-set baseline. Our proposal instead is that the temporal asynchrony in the preview condition introduces a further factor not present in the half-set baseline, and this disrupts search, that is, a ‘difference’ signal between the old and new distractors. We suggest that this difference signal competes with the

difference signal generated by the target (relative to both old and new distractors), slowing the selection of the target and rejection of the new distractors.

There are alternatives to our account stressing grouping and difference signals between competing groups. For example, let us assume that participants adopt an anticipatory set to the new items (cf. Braithwaite & Humphreys, 2003). It is possible that there is a cost associated to setting an anticipatory set for a steep target, if the distractors appearing with the target are also steeper than the items being ignored. This may mean that new distractors are sometimes selected instead of targets. A related idea is that participants are using different search strategies in the preview and full baseline conditions. In particular, in the preview condition participants may set themselves for a singleton target, as in the half-set baseline. However, the fact that the target appears amongst both the preview and search distractors means that new distractors may be coded as singletons relative to the old items in the preview. There then may then be a cost relative to the full baseline in which the only singleton was the target (cf. Bacon & Egeth, 1994). In Experiments 2–4 we develop and assess these separate proposals. In addition, in Experiment 5 we investigate the time-course of the negative preview effect. We ask whether search performance is improved at longer SOAs, as is typical in preview search (Watson & Humphreys, 1997).

3. Experiment 2: Preview search for a steep orientation target with symmetrical shallow distractors

In the categorical search task used here, participants may adopt an anticipatory set to detect the steepest item. Braithwaite and Humphreys (2003) showed that such an anticipatory set could influence performance in preview search. They reported that it was relatively difficult to find a target whose surface features matched the features of preview items that were being ignored. However, this negative impact of feature-similarity was largely over-ridden if participants could anticipate the colour of the target. In Experiment 1 here, an anticipatory set to select the steep target could have led to the selection of the some new distractors, when the new distractors were steeper than the old distractors—that is, with 70°L items in the preview (preview condition B). Statistically, preview condition B was significantly slower than preview condition A in which the 50°R distractors appeared first ($F(1, 29) = 12.766$, $p < .005$), as well as the full-set baseline. Thus, it is possible that the RT cost over the full-element baseline in preview condition B may be a result of the differing steepness of the two distractor types. In particular, when the distractors in the new set are steeper than distractors in the old set, the new distractors may sometimes capture attention (matching any anticipatory set for the target). The experiment described here sought to investigate this by equating the steepness of the two distractor types at 50° from the vertical for both left and right oriented distractors (cf. Fig. 4).

¹ Wolfe (1998) classes difficult search as more than 10 ms/item.

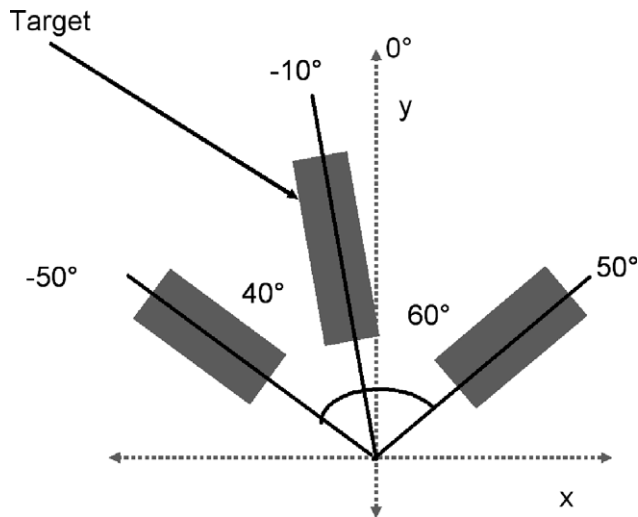


Fig. 4. The orientations of target (10°L) and distractors (50°L and 50°R) for Experiment 2, with the y-axis as the origin.

3.1. Method

3.1.1. Participants

Thirteen females and five males between the ages of 18 and 33 (two left-handed) participated in the study. All had normal or corrected-to-normal vision.

3.1.2. Stimuli, design and procedure

All experimental conditions and procedures were the same as Experiment 1, apart from the configuration. The configuration in Experiment 2 was as follows (Fig. 4). The angular difference between the target (10°L of the vertical) and left oriented distractor (50°L from the vertical meridian) was 40° and the right oriented distractor and target 60° (50°R). Hence, the angular difference between the distractors was 100°.

3.2. Results

Three percent of RTs were removed as outliers. Fig. 5 shows the mean correct RTs by condition (preview A, preview B, full-set, half-set A and half-set B) and display size. Descriptive statistics for the search functions are shown in Table 3. The errors are presented in Table 4. There was no evidence of a speed–accuracy trade-off.

3.2.1. Half-set baselines

Firstly, a two-way ANOVA with condition (condition A, 50°L or condition B, 50°R) and display size as factors was carried out to assess performance in the half-set baselines. This revealed a main effect of distractor identity, $F(1, 34) = 8.34$, $p < .05$. RTs were slower when there was a 50°L distractor (769 ms) than when there was a 50°R distractor (745 ms). There was also a main effect of display size, $F(1, 17) = 8.21$, $p < .05$, with RTs at display size 12 (770 ms) being slower than at 24 (744 ms).

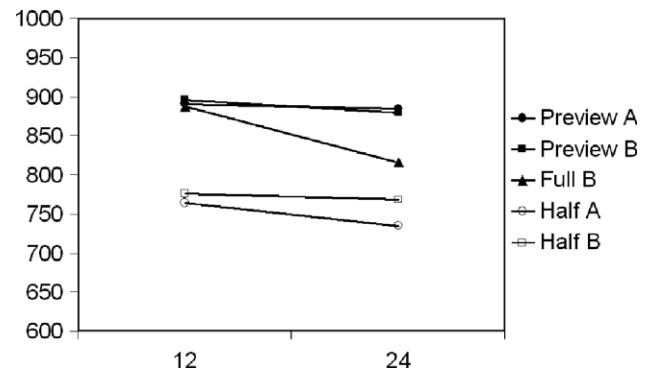


Fig. 5. Mean correct RTs for Experiment 2, preview conditions A (50°L search distractors) and B (50°R search distractors), half-element baselines A and B and the full-element baseline. RTs shown are for display sizes 12 and 24.

Table 3

Mean correct RTs in ms and slopes in ms/item for Experiment 2, preview conditions A and B, half-element baselines A and B and the full-element baseline

Condition	A(50°L)		B (50°R)		Full
	Preview	Half	Preview	Half	
Mean	888	750	888	772	852
Slope	−0.5	−2.4	−1.4	−0.7	−5.9

RTs shown averaged over both display sizes.

Table 4

Percentage errors for Experiment 2, preview conditions A and B, half-element baselines A and B and the full-element baseline

Condition	A (50°L)		B (50°R)		Full
	Preview	Half	Preview	Half	
12	4.4	3.6	4.4	4.3	5.2
24	5	4.7	4.3	5.5	5.2

There was no interaction between display size and display condition.

3.2.2. Preview vs. half-set baselines

A three-way $2 \times 2 \times 2$ ANOVA on RTs assessed the factors: preview condition (preview and half-set baseline), condition A and B (50°L or 50°R search distractors) and display size. RTs were 127 ms slower in the preview condition than in the half-set baseline, $F(1, 17) = 36.684$. No other main effects or interactions were significant.

3.2.3. Preview condition A (50°L) vs. full-set baseline

A two-way repeated measures ANOVA compared preview condition A against the full-set baseline. There was no main effect of preview, but RTs at display size 12 were slower than those at display size 24, $F(1, 17) = 11.884$, $p < .005$. Importantly, there was a preview by display size interaction, $F(1, 17) = 10.381$, $p < .005$. At display size 12, the full-set baseline was 6 ms faster than the preview condition, however at display size 24, the RT advantage was 69 ms for the full-set baseline.

3.2.4. Preview condition B (50°R) against the full-set baseline

In preview condition B, RTs were overall 36 ms slower than in the full-set baseline, $F(1, 17) = 7.688$, $p < .05$. RTs at display size 12 were slower than those at 24, $F(1, 17) = 17.162$, $p < .005$. Again there was a preview by display size interaction, $F(1, 17) = 5.892$, $p < .05$. For display size 12, the full-set baseline was 9 ms faster than the preview, and for display size 24, the full-set baseline was 63 ms faster.

3.3. Discussion

The data match those for preview condition B in Experiment 1. There was a significant RT cost in the preview condition over the full-element baseline, which was particularly pronounced at the larger display size. It was hypothesised that, in Experiment 1, an anticipatory set for a steep item might sometimes have resulted in selection of a steeper search distractor, when all the items in the search set were steeper than the items in the preview set. On this view, performance should be improved in the preview condition here, relative to the full-set baseline search condition, since the two sets of distractors had the same slope. However, the equivalent steepness of the left and right distractors did not eliminate the preview cost from search performance. This argues against the cost being caused by an anticipatory bias to steep stimuli. The continued disruptive effect of the preview, relative to the full-set baseline, is however consistent with the preview breaking-up spatial grouping that is otherwise helpful to full-set search.

This still leaves the question of why preview search differs from the half-set baseline. As argued previously, this last result suggests that temporal asynchrony alone is not sufficient to cause the negative preview benefit, since temporal segmentation between the old and new items should render the preview condition equivalent to the half-set baseline. In Experiment 3 we explored a further account of why targets were slower to detect in the preview condition relative to the half-set baseline. Here, we tested whether a difference signal between the distractors in the preview and the new distractors in the search display, provided competition for selection with the target in the new search set.

4. Experiment 3: Preview search for a steep orientation target with homogeneous distractors

In Experiment 3, we used identical sets of distractors in the new and old displays in preview search. From Experiment 2 we argued that a difference signal between the old and new distractors, based on new distractors being steeper than the old items, was not the cause of the search cost for preview displays (since old and new distractors had the same slopes). Nevertheless, the preview and new distractors still differed from one another in Experiment 2; hence a ‘difference’ signal could still be computed between the dis-

tractors. This was avoided in Experiment 3 by having identical old and new distractors. If a difference signal between the old and new distractors was crucial, the preview cost should be eliminated here.

4.1. Method

4.1.1. Participants

Twelve females and six males between the ages of 18 and 33 (one left-handed) participated in the study. All had normal or corrected-to-normal vision.

4.1.2. Stimuli, design and procedure

The experimental conditions and procedures were the same as Experiment 2, apart from distractor heterogeneity. In this experiment the same distractors were used as preview and new items, i.e. distractors were homogeneous across the preview. In distractor condition A, the 50°L items were used as preview and search distractors. For distractor condition B, the 50°R distractors were used. There were two separate full baselines for each type of distractor, as well as the two separate preview and half-set baseline conditions. All experimental conditions apart from response and display size were blocked. Participants were informed of the identity of the search distractor at the start of each block (Tables 5 and 6).

4.2. Results

The outlier procedure removed 2.4% of the total number of RTs. Errors were low overall (see Table 10) and showed no evidence of a speed–accuracy trade-off. Two ANOVAs were performed on RTs and errors. Firstly, to compare the preview and half-set baselines, a three-way ANOVA with preview condition (preview or half-set baseline), distractor identity and display size was conducted. A second three-

Table 5

Mean correct RTs in ms and slopes in ms/item for Experiment 3, preview conditions A and B, half-element baselines A and B and the full-element baseline

	A (50°L)			B (50°R)		
	Preview	Half	Full	Preview	Half	Full
Mean	736.6	815.6	727.89	735.25	740.99	815.57
Slope	−3.9	−6.44	−5.59	−2.56	−5.13	−3.3

RTs shown averaged over both display sizes.

Table 6

Percentage errors for Experiment 3, preview conditions A and B, half-element baselines A and B and the full-element baseline

	A (50°L)			B (50°R)		
	Preview	Half	Full	Preview	Half	Full
12	5.2	4.4	6	5.2	4.2	7
24	5.7	7.6	6	6.8	5.2	4.4

way ANOVA compared the preview and full-set baselines in a similar manner. Analysis of errors showed no significant differences between the conditions.

4.2.1. Preview vs. half-set baselines

Responses in the preview condition were significantly faster than in the half-set baseline (736 ms vs. 815 ms), $F(1, 17) = 9.601$, $p < .01$. Further, there was also an effect of display size; RTs to 12 item displays being slower than those to 24 item displays, $F(1, 17) = 15.189$, $p < .001$. However there was no effect of distractor identity (distractor A vs. distractor B) and no higher order interactions.

4.2.2. Preview condition vs. full-set baseline

There was no significant RT difference overall between the preview and full-set baseline, $F(1, 17) < 1.0$, $p > .9$ here. Again, 24-item displays were faster than 12-item displays, $F(1, 17) = 16.102$, $p < .001$. There were no other main effects or interactions.

4.3. Discussion

There are two results to note. One is that the preview cost, relative to the full-set baseline, was eliminated. The second is that search was overall slower in the half-set baseline than in the other conditions. We consider this last result first. The slower RTs in the half-set baseline compared to the full-set baseline would arise if search benefited from the presence of more distractors (and especially when distractors were homogeneous, as here). In Experiments 1 and 2 we reported a tendency for RTs to become faster at larger display sizes and the present result is consistent with this. The pattern of data would arise if search benefits from stronger grouping between the distractors, or from local feature differences between the target and distractors being easier to compute, as the display size increased.

Now consider the lack of difference between the preview and the full-set display. We assume that the preview condition would be similar to the half-set baseline, if the new items were simply attended on the basis of temporal segmentation cues (Jiang et al., 2002) or because of new onset capture (Donk & Theeuwes, 2001). However, RTs were quicker than this. This suggests that items from the preview were used to some degree, as were the extra distractors in the full-set baseline. Two possibilities suggest themselves. One is that, when the old and new distractors were the same, participants may have prevented onset capture or temporal segmentation. This goes against the idea that these processes may operate automatically. Alternatively, participants may inhibit old distractors when they may compete for search—a process termed ‘visual marking’ (Watson & Humphreys, 1997). However, when the old distractors were not disruptive, having identical features to those of new distractors, then participants may be able to prevent inhibition from taking place. This in turn enables the old distractors to participate in the extra grouping

and/or local feature computations that benefited search relative to the half-set baseline. Note that proponents of inhibitory visual marking propose that it is a top-down intentional process, applied particularly when old distractors would impair search for new targets (Watson & Humphreys, 1997; Watson et al., 2003). Whichever account is maintained, the data are consistent with the cost in the preview condition being due to a difference signal computed between the old and new distractors, which may provide competition for selection with the new target. Eliminating this difference signal, by making the old and new distractors identical, eliminates the preview cost.

In Experiment 4, we examined another factor that have contributed to the cost to preview search in earlier conditions, namely whether it was due to participants adopting a ‘singleton’ search mode. Following Bacon and Egeth (1994), current models of visual search distinguish between two modes of target detection, singleton and feature search. In singleton detection, the attentional system is set to detect targets differing from the distractors by virtue of one feature, e.g. a red item amongst green, or as here, items of one orientation against another. In other search contexts, distractors may be heterogeneous and so search for an odd-one out target is not possible. In such a case it is necessary to search for a specific feature value. Bacon & Egeth showed that a singleton distractor did not capture attention when participants needed to search for a particular feature value. In contrast, a singleton distractor had a negative impact when participants searched for an odd-one out target. It may be the case that participants used different search modes here. With heterogeneous distractors in the full-set baseline, a feature search mode may be adopted. In preview displays, the target appears as an odd-one out in terms of the new items in the displays. Hence, participants may adopt a singleton detection set and this may be important for the search cost relative to the full-set baseline. In particular, it may only be under the ‘singleton’ search mode that difference signals between the old and new distractors, as well as between the target and distractors, are available, and compete to determine the items first selected. To evaluate this possibility, in Experiment 4 we sought to ensure that participants used the same feature search mode in preview and full-set baselines. We did this by using both orientations of distractor in the preview and search set. If the RT cost in the preview condition over the full-baseline in Experiments 1 and 2 is due to the use of a singleton detection mode, there should be no such cost in Experiment 4.

5. Experiment 4: Effects with heterogeneous distractors

5.1. Method

5.1.1. Participants

Twelve females and 6 males between the ages of 18 and 33 (3 left-handed) participated in the study. All had normal or corrected-to-normal vision.

5.1.2. Design and procedure

The design of this experiment was similar to that of Experiments 1 and 2. Experiment 4 differed in that, rather than the preview and search items being exclusively one kind of distractor (50°L or 50°R), distractors were mixed both as preview and search items. A preview consisted of both 50°L and 50°R distractors, as did the search items appearing with the distractors.

5.2. Results

The outlier procedure removed 81 or 3.23 % of RTs. Mean correct RTs are shown in Fig. 7. Search function data and errors are shown in Tables 7 and 8 respectively.

5.2.1. Preview vs. half baseline

Despite Fig. 7 appearing to show an advantage for the preview condition over the half-set baseline, a two-way ANOVA with preview and display size showed that none of these differences were significant; either as a main effect or an interaction (all F s < 1.15). There was no effect of errors.

5.2.2. Preview vs. full baseline

A two-way ANOVA with display size and preview (full baseline or preview) as conditions showed neither a main effect of preview nor of display size. However, there was a two-way interaction, $F(1,17) = 8.43$, $p < .05$. From Fig. 6 it can be seen that at display size 12 there was no difference in RTs for the preview and full baseline, while at display size 24, there was a 87-ms cost for the preview over the full baseline, $t(1,17) = 3.50$ $p < .005$. Again there was no effect in the error data.

5.3. Discussion

As with Experiment 3, the full-set baseline was faster than the half-set baseline. This again demonstrates that search benefits when the display size is increased. For the preview condition, performance was equivalent to the

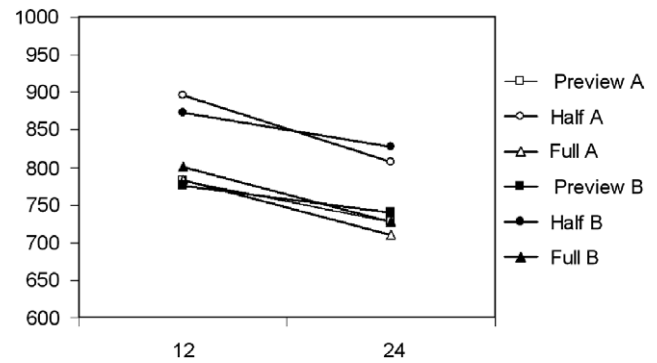


Fig. 6. Mean correct RTs for Experiment 3, preview conditions A (50°L search distractors) and B (50°R search distractors), and corresponding half-element and full-element baselines A and B. RTs shown are for display sizes 12 and 24.

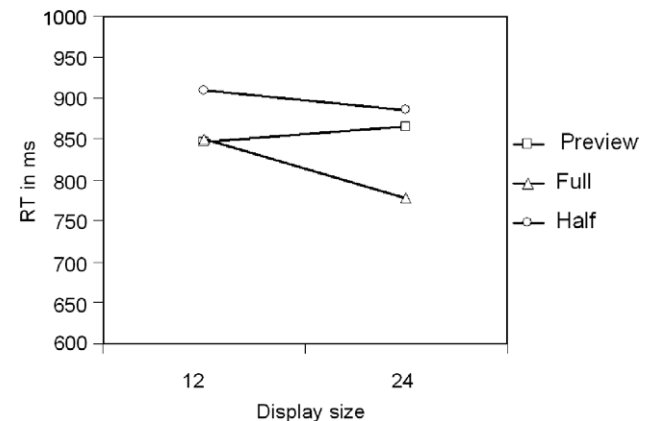


Fig. 7. Mean correct RTs for Experiment 4, preview, half-element and full-element conditions. RTs shown are for display sizes 12 and 24.

Table 7

Mean correct RTs in ms and slopes in ms/item for Experiment 4, preview condition, half-element baseline and the full-element baseline

	Preview	Half	Full
Mean	855.4	897.5	814.1
Slope	1.51	−1.95	−6.05

RTs shown averaged over both display sizes.

Table 8

Percentage errors for Experiment 4, preview, half-element baseline and full-element baseline conditions

	Preview	Half	Full
12	6.7	6.5	6.7
24	5.3	6.5	6.5

half-set baseline. Previously we found that the preview and full-set baseline conditions were slower than the half-set baseline (Experiments 1 and 2), and we proposed that this was due to distractor heterogeneity (Experiment 3). In the experiment here, the preview condition is equivalent to the half baseline as opposed to more rapid as in Experiment 3. Critically, it follows that there was a preview cost relative to the full baseline, particularly at the larger display size.

This cost was unlikely to be due to participants adopting a singleton search strategy in the preview, but a feature (identity-based) search in the full-set baseline. Note that a singleton search mode was made improbable in Experiment 4 by there being two types of distractor with both the preview and the new search display. If a change in search mode was not critical, and if difference signals between the old and new distractors played little part here (see above), then what led to the preview cost relative to the full-set baseline? To account for this cost, we return then to our original proposal that preview conditions disrupt grouping between the (old and new) distractors. In the full-set baseline the distractors can group by dint of both being categorically

different from the target (even though there are two distractor orientations). This grouping effect is demonstrated in the full-set condition being faster than the half-set baseline. In the preview grouping is disrupted by temporal segmentation of the two sets of distractors generating difference signals between them, making performance equivalent to the half-set baseline.

One question outstanding is that if, as we argued above, the effects of temporal segmentation can be switched off in the case of homogeneous distractors in Experiment 3, why can they not be here? This would facilitate categorical grouping between new and old distractors reducing the preview cost over the full baseline. However, although the effects of onset capture or inhibiting the old distractors may be reduced, the very presence of the preview will ensure that a difference signal is produced between the search and preview distractors. Indeed, one may predict that if any prioritisation of the new items over the old is eliminated or reduced this would increase competition between the preview and search items. The result of this would be a greater cost in the preview condition over the full baseline relative to when a process such as visual marking occurs, i.e. prioritisation of the new items/deprioritisation of the old items. We assessed this proposal and whether search performance was consistent with the occurrence of visual marking (cf. Watson & Humphreys, 1997) in Experiment 5, by varying the duration of the preview period.

Watson and Humphreys (1997) showed that the effectiveness of the preview depended on a critical time period; if the preview period was less than 400 ms then the ability of participants to de-prioritise the preview in search decreased. Other studies have reported feature-based carry-over effects in preview search, with targets being difficult to detect if they carry the features of old distractors (Braithwaite et al., 2003). Such carry-over effects are reduced when previews are presented more briefly (e.g. Braithwaite et al., 2005; Olivers & Humphreys, 2003). Carry-over effects could be due to the new stimuli grouping with the old stimuli on the basis of their having common features. However, this spatial grouping effect should be stronger, not weaker, with a shorter interval between the new and old items, since temporal segmentation of the displays should reduce with a short interval. In contrast, the long time-course is consistent with (i) carry-over effects being due to lingering suppression of the features of stimuli in the preview which is passed onto similar new items, and with (ii) this suppression taking time to build up (cf. Watson & Humphreys, 1997). The result is not consistent with the temporal segmentation and onset-capture accounts of preview search (Donk & Theeuwes, 2001; Jiang et al., 2002), since temporal segmentation and onset capture should be achieved long before the interval needed to maximise the preview benefit (see Yantis & Gibson, 1994, for evidence). To test the time-course of the preview cost, we evaluated performance with long and short preview durations (200 and 1000 ms).

6. Experiment 5: The effect of varying preview-search display SOA

Given prior studies of preview search, we expect that a preview shorter than 400 ms or so is not sufficient to allow the full build-up of any inhibition of the old items (cf. Watson & Humphreys, 1997; see also, Humphreys et al., 2004; Humphreys, Jung-Stalmann, & Olivers, 2004a). This should mean that, with a short duration preview, more old items should be available to influence selection of the new stimuli. If there is additional grouping of these old distractors with the new distractors, then categorical search may benefit. The preview condition should be faster with a 200-ms preview than a 1000-ms preview and any preview costs compared with the full-set baseline should be less at 200 ms.

Recently, however, Braithwaite et al. (2005) have provided evidence that, in addition to slow-acting suppression of previewed items there is also rapid formation of groups of old and new distractors. For example, there are biases against probes that fall on old rather than new groups, which occur with short preview durations; the strength of this bias then increases over time, as marking takes place. Now, if there is fast-acting temporal segmentation and separate formation of groups of old and new distractors, then grouping between the old and new distractors may be disrupted even with a 200-ms preview. It follows that there will be an RT cost relative to the full-set baseline due to both grouping being disrupted and difference signals between the groups competing for selection with the target. However, at the longer preview duration, visual marking may contribute to performance, especially when the old distractors could compete for selection. If the old items are suppressed, so the competition for selection will reduce, with the consequence that performance in the preview condition improves over time. These ideas were tested here.

6.1. Method

6.1.1. Participants

Ten females and six males between the ages of 18 and 33 (none left-handed) participated in the study. All had normal or corrected-to-normal vision.

6.1.2. Stimuli, design and procedure

The stimuli used were the same as Experiments 2–4. As before there was a display size condition of either 12 or 24 items and participants responded to a break in a circle located centrally within the target. Three different preview-search set SOAs were used; 0 ms (the full-element baseline), 200 and 1000 ms, blocked and presented in random order. Displays consisted of either the left distractors (50°L) first followed by the right oriented distractors (50°R) appearing with the target, or a right distractor preview followed by the target and left distractors. There were 16 trials in each condition giving a total of 320.

6.2. Results

Due to an unacceptably large error rate (over 20%), 2 of the 16 participants were removed from the subsequent analysis and 2.74% of correct RTs were removed as outliers. Mean correct RTs are shown in Fig. 8, and these were entered into a two-way within subjects ANOVA with display size, SOA and display condition (A or B) pooled as factors as there was no preview order difference in the full-element baseline. This gave a 5×2 ANOVA.

There was no effect of display size, $F(1,13) = 3.07$, $p > .1$, but there was a main effect of display condition, $F(4,52) = 5.74$, $p < .005$. RTs were slowest for preview condition A in the 200 ms preview condition (767 ms) followed by preview condition B, 200 ms (741 ms). The full-set baseline (694 ms) and 1000 ms preview conditions (A, 706 ms; B, 709 ms) were at least 30 ms faster than the 200 ms preview conditions. The interaction between display size and condition was not significant, $F(4,52) = 1.987$, $p > .10$ (see Table 9). Planned comparisons were carried out to compare the 200 ms preview condition with the 1000 ms preview and the full-set baseline, averaging over the two preview conditions A and B and display size. The 1000 ms preview condition (708 ms) was significantly faster than the 200 ms preview condition (753 ms), $t(13) = 3.1$, $p < .01$ and the 200 ms preview condition was significantly slower than the full baseline (694 ms), $t(13) = 2.91$, $p < .05$.

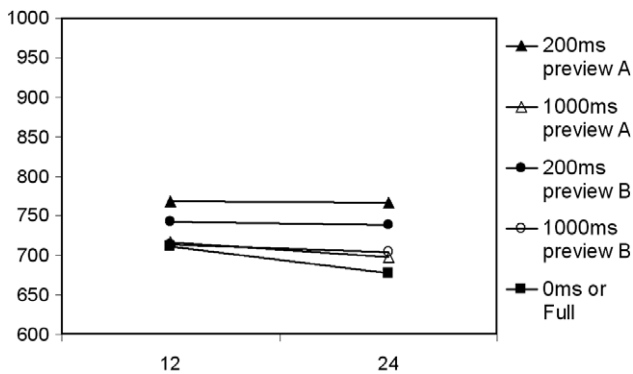


Fig. 8. Mean correct RTs for Experiment 5, preview conditions A (50°L search distractors) and B (50°R search distractors) at 200 and 1000 ms and the full-element element baseline.

Table 9

Mean correct RTs in ms and slopes in ms/item for Experiment 5, preview conditions A and B at 200 and 1000 ms preview, and the full-element baseline

	A (50°L)		B (50°R)		0 ms or full
	200 ms	1000 ms	200 ms	1000 ms	
Mean	767.5	706.5	740.5	709	694
Slope	-0.1	-1.6	-0.4	-0.8	-2.8

RTs shown averaged over both display sizes.

Table 10

Percentage Errors for Experiment 5, for preview conditions A and B at SOA, 200 or 1000 ms and the full-element baseline, for display sizes 12 and 24

	A (50°L)		B (50°R)		0 ms or full
	200 ms	1000 ms	200 ms	1000 ms	
12	6.7	7.2	6.5	5.8	5.3
24	5.5	5	9.6	6.7	6.2

6.3. Discussion

There are two interesting aspects of these results. The first is that RTs in the 200 ms preview condition were significantly slower than in the full-element baseline. That is, the preview cost was established at a short preview duration—a duration previously found to be too short to maximise preview search (Humphreys et al., 2004; Watson & Humphreys, 1997). If the cost in the preview condition is attributed to the break-up of grouping between the two sets of distractors, and to competition with the target from difference signals between the old and new distractor groups, then these results suggest that this break-up was achieved within 200 ms. The second result is that, relative to the short preview condition, RTs were speeded when the preview duration increased; RTs then fell between the cost established with a 200-ms preview and the full-set baseline. This speeding of performance in the 1000 ms preview condition cannot easily be explained in terms of either attentional capture by new items or temporal grouping alone. The 200 ms preview should be sufficient to produce temporal segmentation between the two displays, and to allow onset capture to occur (Yantis & Gibson, 1994). Despite this, performance improved as the preview duration increased. This is consistent with there being a relatively slow build-up of suppression to the old stimuli, reducing their competition for selection with the new search display (Watson & Humphreys, 1997).

From these results we conclude that two factors are at play. One is the segmentation and interruption of categorical grouping of the old and new items in preview displays. This appears to be relatively fast-acting and can lead to preview search being slowed when compared to a full-set baseline—at least under circumstances in which grouping between all the distractors in the full-set condition contributes positively to search. The second factor is inhibitory suppression of the old items (visual marking). This process has a longer time-course than the grouping process, but leads (over time) to old items having a reduced impact on search, since the group of old distractors then competes less for selection with the group of new items.

7. General discussion

This paper set out to explore the role of distractor grouping in categorical orientation search. Using preview

displays to disrupt grouping between categorically similar but featurally different distractors we found:

- (1) An RT cost for preview search, relative to a full-set baseline, when the target could be categorised as steep and all the distractors shallow (Experiments 1 and 2);
- (2) This cost was not due to new distractors appearing closer to the target-defining attribute, relative to the old distractors (i.e., if the old distractors were shallow, the new distractors steeper, and the target steep). Experiment 2 showed a slowing of preview search even when the old and new distractors had matching orientations;
- (3) That there was no cost of the preview over the half- and full-set baselines when the preview and search distractors were the same group (Experiments 3 and 4). In this case, difference signals between the old and new distractors were minimised, indicating that such differences contributed to the costs in preview search;
- (4) When preview and search items were homogeneous there was no effect of temporal asynchrony, preview search was indistinguishable from the full-set baseline (Experiment 3), and both were faster than the half-set baseline. This indicates that there was not automatic onset capture by new items or automatic attention to temporally segmented groups;
- (5) That if participants were forced to use feature search mode in both preview and full baselines, that the cost for the preview condition over the full baseline was still apparent (Experiment 4);
- (6) The cost in the preview condition was greater when the preview appeared briefly (200 ms) relative to when the preview duration was longer (1000 ms) (Experiment 5).

7.1. Categorical orientation search

Our experiments support a role for grouping in categorical orientation search. Preview displays can disrupt the grouping process between categorically similar shallow distractors slowing search RTs relative to when all the distractors appear (and group) together. Orientation search, in which the target is categorically unique, is not simply a matter of the top-down monitoring of a perceptual channel (Hodsoll & Humphreys, 2005). The grouping and rejection of distractors within the same orientation category also appears to be significant factor.

Importantly, Experiment 3 showed that temporal segmentation itself was not sufficient to slow search in the preview. When new and preview distractor items had the same orientation there was no effect of temporal asynchrony compared with the full-set baseline. What appears to be crucial is that the distractors in the old and new groups differ from one another. This then gives two sources of differ-

ence signal, (i) between the target and the distractors, and (ii) between the old and new distractors. The competition for selection between these signals slows search relative to when all the items appear simultaneously, as in the full baseline.

Hodsoll and Humphreys (2005) showed that the advantage in orientation search for a target that is categorically differed from the other items depended on top-down knowledge of the target. They failed to find efficient search for targets differing in orientation category from distractors when the target was unknown. However, if grouping operates within orientation-categories, as suggested here, then why was there not at least some advantage for unknown, categorical targets? One possibility is that the grouping effects shown here are dependent on target knowledge also. If coding of a target as uniquely steep or shallow is done in a top-down manner, then coding of distractor items as all shallow or steep may depend on the same process. In their Search by Recursive Rejection model, Humphreys and Müller (1993) modelled that search by having a target template (a description of the target features) modulate grouping processes. Similarly here, a categorical template for a steep target may modulate grouping between categorically similar distractors.

One can speculate as to whether the preview effects found here are specific to the orientation dimension or whether they would affect categorical grouping in other dimensions such as colour. We have proposed that difference signals generated between the preview and new distractors disrupt selection. Such difference operators are thought to be local in extent (Bravo & Nakayama, 1992) in that the magnitude of the difference signal is greatest when they are proximal rather than far. Nothdurft (2000) too showed that the salience of an orientation target is greatest with relatively dense texture arrays, consistent with local lateral interactions sharpening the response to an 'odd' stimulus. However, Nothdurft found only small variations with texture density in the salience of a target defined by its luminance, suggesting that the spatial range of luminance contrast mechanisms are smaller than those coding orientation.

7.2. Implications for preview search

Our data have shown two novel results in terms of preview search. In Experiments 1, 2, 4 and 5, preview displays had a negative impact on preview search relative to the full-set baseline. On the other hand, Experiment 3 showed that preview displays had no effect on search with homogeneous distractors relative to the full-set baseline, though both conditions were faster than the half-set baseline. This last result (full-set RT < half-set RT) demonstrates that the extra distractors helped to facilitate search, and this held for the preview too (preview RT < half-set RT). Thus, despite the temporal segmentation between the preview and search items, participants could still use the preview items to facilitate search. This goes against the idea that

there is automatic capture of attention by the new items, and/or automatic attention to the new temporal group (cf. Donk & Theeuwes, 2001; Jiang et al., 2002). Instead, we suggest that there was a contribution to performance from inhibitory visual marking (Watson & Humphreys, 1997). Moreover, marking is only applied when old distractors are likely to be detrimental to search (i.e., when they differ from items in the new display; see Humphreys et al., 2004, for evidence). If marking is not applied when the old and new distractors are identical (as in Experiment 3), then old items will be available to group with identical new distractors, facilitating search compared with the full-set baseline.

Experiment 5 explored performance when short as well as long preview durations were used. Here the preview cost was maximal with a short preview duration, and RTs improved as the preview duration lengthened. To account for this we proposed that there is rapid-acting grouping into old and new distractor groups, with differences between these two groups slowing target selection. This is found with the short preview duration. At the longer preview duration performance is affected by visual marking, applied to reduce any competition for selection from old stimuli. By suppressing the old items, competition for target selection is reduced and RTs are facilitated. This argument, for fast grouping and segmentation, followed by a slower-acting process of voluntary suppression, fits with recent data from Braithwaite et al. (2005) using probe-dot detection. Braithwaite et al. found a bias against old items even with short-duration previews, which subsequently increased with the preview duration. It also fits with prior data suggesting that temporal segmentation operates within 200 ms (Yantis & Gibson, 1994). Our data show also that, following any initial segmentation, there can be additional effects of inhibitory marking of the old items, which operates across a longer time-course (Humphreys et al., 2004; Watson & Humphreys, 1997). Inhibition of the old items suppresses the effect of the orientation difference signal between the new and old distractors facilitating search. The data also suggest that visual marking may be helpful in maintaining any segmentation between the old and new items, when the new items appear after a long interval. Experiment 3 demonstrated that temporally distinct old and new items could be integrated, when the old items had the same features as new distractors. Under these circumstances, it may not be useful to maintain marking on old stimuli, so they can be integrated with the new items.

8. Summary

The results suggest a role for distractor grouping in categorical orientation search, with grouping (and performance) being disrupted under preview conditions. Grouping and segmentation of new and old stimuli is fast-acting, and can cause competition for selection when the old and new groups differ. The effects of competition decrease over time, consistent with a process of visual

marking under preview conditions. However, marking is not necessarily applied when old distractors do not compete for selection, which then allows old and new distractor features to be integrated. The results suggest that there is flexibility in whether previews are used in search, and argue against automatic temporal segmentation and attention capture by new stimuli.

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References

- Bacon, W. F., & Egeth, H. E. (1991). Local processes in preattentive feature detection. *Journal of Experimental Psychology: Human Perception and Performance*, 17, 77–90.
- Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Perception and Psychophysics*, 55(5), 485–496.
- Braithwaite, J. J., & Humphreys, G. W. (2003). Inhibition and anticipation in visual search: evidence from effects of color foreknowledge on preview search. *Perception & Psychophysics*, 65(2), 213–237.
- Braithwaite, J. J., Humphreys, G. W., & Hodsoll, J. (2003). Color grouping in space and time: evidence from negative color-based carry-over effects in preview search. *Journal of Experimental Psychology: Human Perception and Performance*, 29(4), 758–777.
- Braithwaite, J. J., Humphreys, G. W., & Hulleman, J. (2005). Color-based grouping and inhibition in visual search: evidence from a probe-detection analysis of preview search. *Perception & Psychophysics*, 67(1), 81–101.
- Bravo, M., & Nakayama, K. (1992). The role of attention in different visual search tasks. *Perception & Psychophysics*, 51, 465–472.
- Donk, M., & Theeuwes, J. (2001). Visual marking beside the mark: prioritizing selection by abrupt onsets. *Perception & Psychophysics*, 63, 891–900.
- Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review*, 96, 433–458.
- Duncan, J., & Humphreys, G. W. (1992). Beyond the search surface: visual search and attentional engagement. *Journal of Experimental Psychology: Human Perception and Performance*, 18, 578–588.
- Foster, D. H., & Ward, P. H. (1991). Asymmetries in oriented-line detection indicate two orthogonal filters in early vision. *Proceedings of the Royal Society of London, Series B Biological Sciences*, 243, 75–81.
- Gibson, B., & Jiang, Y. (2001). Visual marking and the perception of salience in visual search. *Perception & Psychophysics*, 63(1), 59–73.
- Hodsoll, J. P., & Humphreys, G. W. (2005). The effect of target foreknowledge on visual search for categorically separable orientation targets. *Vision Research*, 45(18), 2346–2351.
- Humphreys, G. W., Jung-Stalmann, B., & Olivers, C. N. L. (2004a). An analysis of the time course of attention in preview search. *Perception & Psychophysics*, 66(5), 713–730.
- Humphreys, G. W., Kyllinsbæk, S., Watson, D. G., Olivers, C. N. L., Law, I., & Paulson, O. (2004). Parieto-occipital areas involved in efficient filtering in search: a time course analysis of visual marking using behavioural and functional imaging procedures. *Quarterly Journal of Experimental Psychology*, 54(A), 610–635.
- Humphreys, G. W., & Muller, H. J. (1993). Search via Recursive Rejection (SERR): A connectionist model of visual search. *Cognitive Psychology*, 25, 43–110.
- Jiang, Y., Marks, L. E., & Chun, M. M. (2002). Visual marking: selective attention to asynchronous temporal groups. *Journal of Experimental Psychology: Human Perception and Performance*, 28, 717–730.

- Nothdurft, H. C. (2000). Saliency from feature contrast: variations with texture density. *Vision Research*, 40, 3181–3200.
- Olivers, C. N. L., & Humphreys, G. W. (2003). Visual marking inhibits singleton capture. *Cognitive Psychology*, 47(1), 1–42.
- Olivers, C. N. L., Humphreys, G. W., Heinke, D., & Cooper, A. G. C. (2002). Prioritization in visual search: visual marking is not dependent on a mnemonic search. *Perception & Psychophysics*, 64(4), 540–560.
- Olivers, C. N. L., Watson, D. G., & Humphreys, G. W. (1999). Visual marking of locations and feature maps: evidence from within-dimension conjunctions. *Quarterly Journal of Experimental Psychology*, 52(A), 679–715.
- Rosenholtz, R. (2001). Visual search for orientation among heterogeneous distractors: Experimental results and implications for signal-detection theory models of search. *Journal of Experimental Psychology: Human Perception and Performance*, 27, 985–999.
- Sagi, D., & Julesz, B. (1987). Short-range limitation on detection of feature differences. *Spatial Vision*, 2, 39–49.
- Theeuwes, J., Kramer, A. F., & Atchley, P. (1998). Visual marking of old objects. *Psychonomic Bulletin and Review*, 5, 130–134.
- Van-Selst, M., & Jolicoeur, P. (1994). A solution to the effect of sample size on outlier elimination. *Quarterly Journal of Experimental Psychology*, 47A, 631–650.
- Watson, D. G., & Humphreys, G. W. (1997). Prioritising selection for new objects by top-down attentional inhibition of old objects. *Psychological Review*, 104, 90–122.
- Watson, D. G., Humphreys, G. W., & Olivers, C. N. L. (2003). Visual marking: using time in visual selection. *Trends in Cognitive Science*, 7(4), 180–186.
- Wolfe, J. (1998). Visual search. In H. Pashler (Ed.), *Attention*. London, UK: University College London Press.
- Wolfe, J. M., & Friedman-Hill, S. R. (1992). On the role of symmetry in visual search. *Psychological Science*, 3, 194–198.
- Wolfe, J. M., Friedman-Hill, S. R., Stewart, M. I., & O'Connell, K. M. (1992). The role of categorization in visual search for orientation. *Journal of Experimental Psychology: Human Perception and Performance*, 18, 34–49.
- Yantis, S., & Gibson, B. (1994). Object continuity in apparent motion and attention. *Canadian Journal of Psychology*, 48(2), 182–204.